Generation of Synthetic SAR Imagery for ATR Development

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ABSTRACT

Due to increased use of imaging sensors in military aircraft, future combat airplane pilots will need onboard artificial intelligence for aiding them in image interpretation and target designation.
This document presents a system which is able to create high-resolution artificial SAR imagery. The resulting images can be used to facilitate automatic target recognition (ATR) algorithm development. The system provides an interface that allows dynamically requesting imagery depending on the location and heading of a simulated carrier platform. Landscapes, structures and target signatures are generated based on digital terrain elevation and cultural data and 3d models. Post-processing algorithms for overcoming weaknesses of digital terrain databases and improving image realism are presented.
Simulated sensor imagery is useful in a wide range of applications, two of which are training of ATR algorithms and sensor simulation in flight simulation environments.
Using an existing ATR method as an example, the applicability and the influences of synthetic imagery on ATR training are shown and first approaches how to validate the correctness of the imagery are outlined. The integration of the system into a flight simulator in the context of interfacing and control topics is presented as another example for its applicability. As an outlook, an example of using external databases for creating imagery of crisis areas is outlined.

Keywords: SAR sensor simulation, ATR training, digital terrain database, cockpit simulation

1. INTRODUCTION

1.1. SAR image interpretation

Currently most military SAR sensors are installed in reconnaissance satellites or airplanes. These sensors obtain high-resolution imagery of a target area and transfer it to ground stations where specially trained professional image interpreters scan these data for man-made objects. The results are then used to plan and execute precision attack missions. After the attack, damage assessment can be done on newly gathered imagery.

Future combat aircraft are expected to display a self-targeting capability which denotes the ability to run through the entire chain of sensor deployment, image interpretation, target designation, mission planning and execution all on their own. This puts a lot of additional workload on the pilot who would have to scan huge images for potential targets while flying through or close to enemy territory.

Another important issue is that SAR imagery looks quite different compared to the classical optical images that pilots are used to. In order to reduce the workload on the pilot it is necessary to aid him by means of automatic image interpretation [1][2].

1.2. Artificial SAR imagery for SAR ATR

We have developed a training-based method for automatic target recognition (ATR) which can be used for visual, infra-red as well as SAR imagery. This ATR system is an ensemble of neural networks with Gaussian and Laplacian image pyramids as pre-processing steps. It is described in detail in [3].

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Because of its learning-based approach, our method requires the existence of realistic and diverse imagery with detailed knowledge about the objects depicted in the image. In SAR imagery, object signatures change drastically depending on their orientation to the radar beam. They are also changed by pixel correlation and speckle effects.
In order to counter these problems, the ATR method must be shown many pictures with different viewing geometries. It is costly and time-consuming to gather real SAR imagery that meets all these preconditions. This was the driving force for the development of the SAR simulator at the military aircraft business unit at EADS.

2. THE SAR SIMULATOR AT EADS

2.1. System requirements

The goals mentioned above impose several design requirements on the system. Of course it must allow for the realistic simulation of landscapes and man-made objects, an exact definition of which is still to be developed (see paragraph 3). For the simulation of different sensors and processing parameters, the basic simulation parameters like bandwidth, sampling frequency and polarisation must be easily configurable. In order to obtain simulated target signatures which are very close to reality, it is necessary to simulate SAR specific effects like noise, speckle, foreshortening, layover, corner reflector effect and edge currents.
The goal of integrating the SAR simulation into a flight simulator environment introduces further requirements to the simulation like short processing time (order of seconds to minutes), connection to a terrain database and accessibility of the provided services via a network .

2.2. Basic components

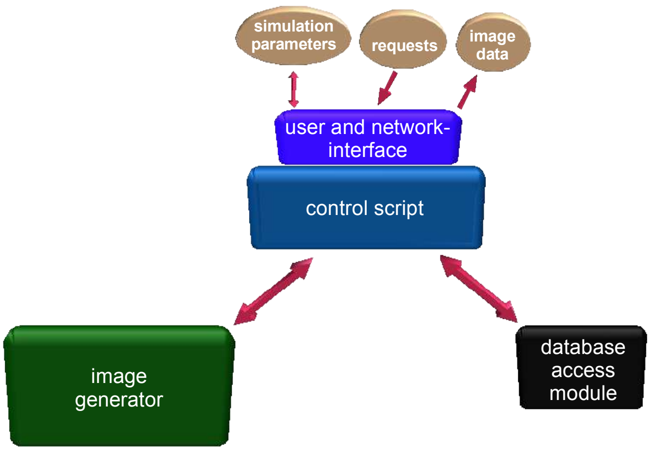


Figure 1 Basic components

The SAR simulator consists of three main modules: image generator, control script and database control. The *image generator* module is responsible for the generation of SAR imagery from the input data. These data are created by the *database control* module, which extracts them from *terrain and target database* according to the request that was received by the *control script*. As the name suggests, the control script governs the data exchange between image generator and the database control. But it also provides a network interface for collaboration with external software and a user interface for accessing sensor and processing parameters. Figure 1 illustrates the collaboration of these basic modules. The arrows indicate data and control flow.

2.3. System implementation

The basis of the SAR simulator is an EADS proprietary radar **image generator** called SAR-View. It was originally developed at the DaimlerChrysler research center in Ulm and is still being expanded and developed further. The basic steps that lead to the synthesis of an image using this software are depicted in figure 2:
After a set of terrain data has been extracted from a *terrain database,* a landscape module transforms and interpolates the terrain according to the required resolution of the synthetic image and the viewing geometry (platform heading).

The landscape module uses a *map of height* values to describe the terrain surface and a *map of feature indices* to denote terrain cover like paved road, forest or water. From the orientation of surface elements and their material codes *radiometric expectation values* can be inferred for ground and slant ranges. The target module relies on 3d *CAD models* of man-made objects and uses a combination of geometric and physical optics to calculate radar cross sections (RCS) for the simulated targets.
For the generation of realistic target signatures the 3d models must be very detailed and accurate (at least some thousand surfaces). After the RCS calculation for the targets is finished, the result is integrated with the landscape. Then pixel correlation and speckle effects are computed to give the *synthetic SAR image*.

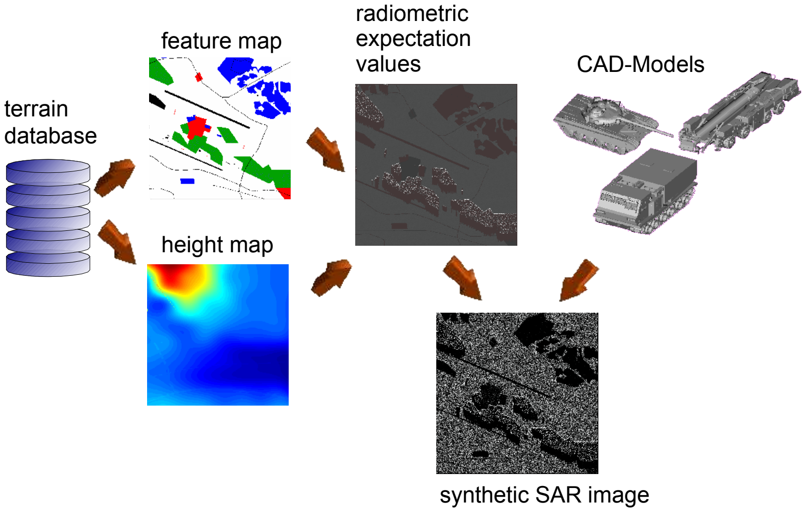


Figure 2 The process of image formation in the SAR image generator

The SAR simulator also contains a **database control** module. Its graphical user interface is illustrated by figure 4. This module supports access to the terrain database and provides terrain and target data in a format that can be processed by

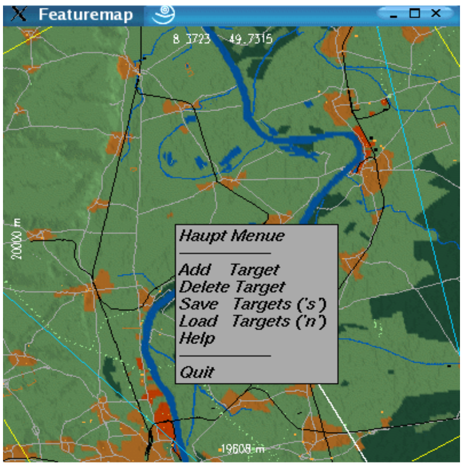


Figure 4 The database access module

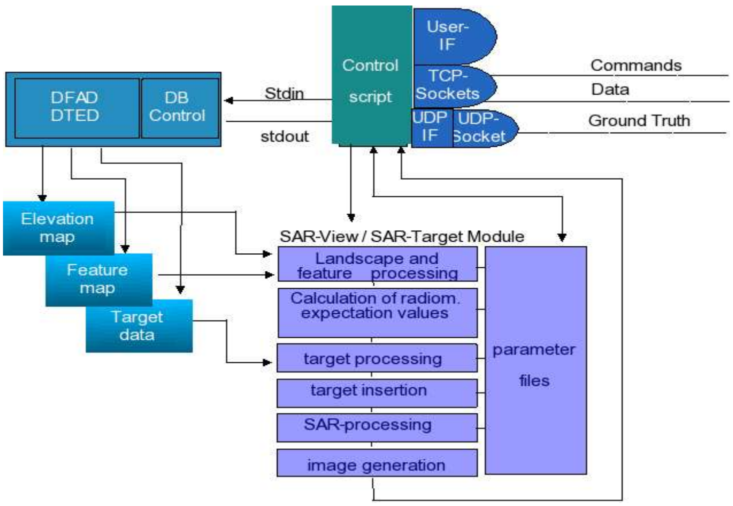


Figure 3 Data flow within the SAR simulator

the image generator. Currently DTED / DFAD level 1 data are used for height and feature data. In the flight simulator environment, this module calculates the irradiated surface area from the current aircraft position and sensor alignment. After that, a height and feature map for the calculated area are extracted from the terrain database. It also calculates if any targets contained in the target database are within the calculated surface area. If there are any targets in the scene, their local coordinates are computed. In standalone mode, this module allows for the placement of targets within the

terrain database. The menus for this mode are shown in figure 4. The target location data are kept in a separate text file for scenario management. This mechanism allows other objects like houses or power line poles to be added to the database.

The **control script** is the superior instance that controls all activities within the SAR simulation software and the communication with external programs. It is written in ExpectK which is a superset of Tcl, TK and Expect functionality. An overview of the data flow between this module and its subordinated programs is shown in figure 3. It handles all simulation parameters, user interaction and network requests.

The script provides a graphical user interface (GUI) for convenient modification of simulation parameters at run-time. The GUI is shown in figure 5. Because of their large number, all controls of the GUI can not be explained here, but it allows adjusting sensor parameters (e.g. chirp bandwidth, carrier frequency, depression angle) and processing parameters (hamming weighting, brightness). It displays target positions within the scene, shows a thumbnail version of the generated image and allows the user to select the desired output data.

If a request for an image is received on the network socket (TCP), the control script provides the database access module with the data needed for the extraction of the chosen terrain area. This communication uses standard unix I/O channels (stdin/stdout). The database access module then computes the target area and generates files containing the elevation and feature maps as well as text files containing target data if there are any in the scene. These files are used by the SAR-View / SAR-Target modules (image generator) to form the imagery according to the adjusted parameters and proceeding through the steps explained in figure 2. The generated image is then sent to the requesting instance via a TCP network socket. For ATR evaluation, ground truth data can be transferred along with the image via a UDP socket. The SAR simulation computer is a Linux based Pentium IV PC driven by two 2.4 GHz CPUs.

After successful integration it was possible to generate SAR pictures of any area in southern Germany (restricted by the size of the terrain database). An example is shown in figure 6. This image has a size of about 1000x1000 pixels. It covers an area of 1500m x 1500m and was made using a simulated sensor depression angle of 20 degrees. The quadratic blocks are flat buildings that have been modeled into the landscape. The time needed to compute this image on the hardware described above was about 10 seconds.

Using the network interface of the control script it is possible to simulate SAR image for any position within the terrain database which is curently restricted to southern Germany but will be expanded soon. A request will contain the position and orientation of the sensor platform and the alignment of the sensor on the platform itself. From these data the simulator will determine the viewing area and generate an image.

2.4.Terrain databases and post-processing

The DFAD / DTED data structure has some drawbacks for the creation of realistic imagery as it models only surface height and cover. Moreover there is no connection between these properties. DTED data do not model elevation with

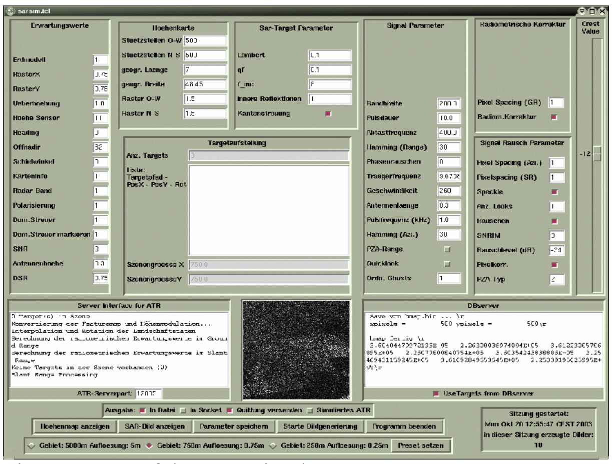


Figure 5 GUI of the SAR simulator

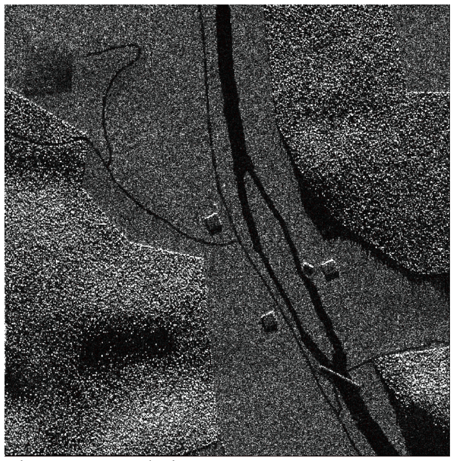


Figure 6 Sample image

respect to surface cover, which means that there will be no height difference between a forest and a bordering meadow. For man-made objects, DFAD only provides technical data (e.g. diameter, height) but no models.

Our SAR simulator overcomes these drawbacks by inserting a post-processing step after the creation of height and feature maps for the viewing area is completed. The feature map is analysed and the height map gets processed according to the knowledge gained in the feature map analysis. For example: in forest areas all surface points are raised by a random value representing the height of tree tops. Road are lifted above their surroundings by half a meter. The following pictures (figures 7 and 8) illustrate the effect of landscape post-processing on the resulting image. The bright area in figure 7 is covered by forest, the quadrilateral structures result from the interpolation of the underlying height model. In figure 8 this forest area looks more 3-dimensional due to the height modulation that has been done. The edge of the forest directed towards the radar sensor lights up brightly like a real forest would and there is a shadow area on the right side of it. In the enlarged areas in figure 8 the upper rim of the road lights up compared to figure 7.
In the case of high resolution imagery (1.5m or better), single trees become visible in the picture. In this case cones of random height can be inserted at random locations within forested areas. This kind of processing is shown in figure 9.

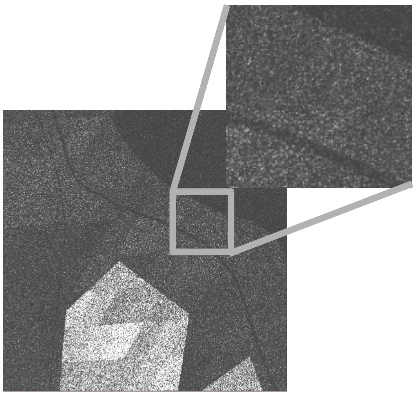


Figure 7 SAR image without landscape post-processing

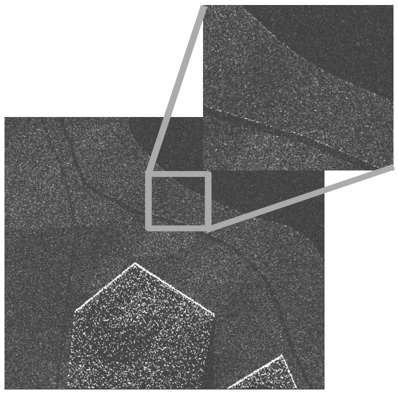


Figure 8 SAR image with landscape post-processing

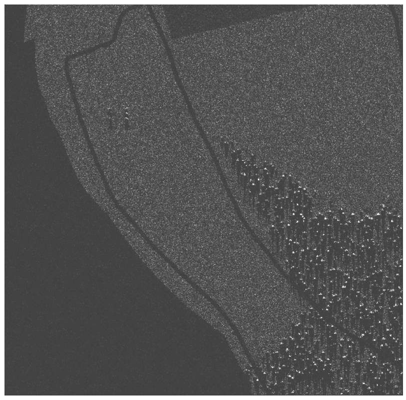


Figure 9 Simulation of single trees for very high resolutions

The images depicted in figures 7 through 13 were created using a depression angle of about 8 degrees in a side-looking geometry . The carrier signal frequency is about 10 Ghz. The carrier platform was flying at a height of about 10 000 m at a speed of about 250 m/s.

The quadrilateral structures in figure 7 are visible not only in the forested area but also on the meadow areas above. These unrealistic effects can be overcome by using a better height interpolation. Figure 10 shows an image using linear interpolation while figure 11 shows a landscape in SAR which has been interpolated using spline curves. Shadows which show up as dark quadrilaterals or triangles in figure 10 look rounded in figure 11. The layover effect that slopes facing the sensor produce can be seen as bright patches around the group of buildings in figure 11 only .

While simulating high resolution imagery using current terrain databases there is a good chance of viewing a homogenous area like a crop field. This problem can be overcome by using height variations that are typical for different crops. Maize will have a different height profile to wheat. These height variations can be modeled directly into the landscape or be used as parameters for determining the corresponding RCS function. Using this approach a homogenous surface can be subdivided into different regions thus looking more realistic.

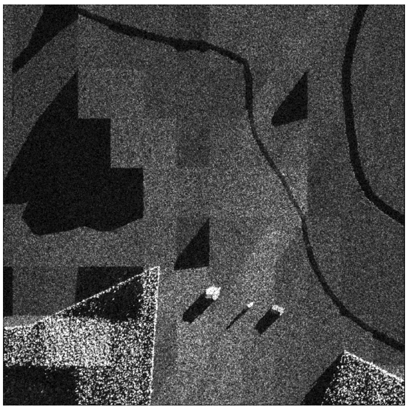


Figure 10 Linear interpolation

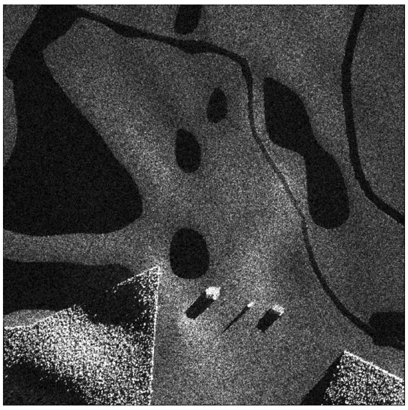


Figure 11 Spline interpolation

DFAD contains only the type and dimensions of man-made objects which is not enough for generating images of such artificial objects. To resolve this, it is possible to extract the positions of power poles, bridges and similar structures from DFAD. In our simulator these data are stored in a text file and, in case one is located in the viewing area, an appropriate CAD model is inserted into the scene. The following pictures (figures 12 and 13) show the effect of replacing a simple height map modulation (using the height information contained in DFAD) with a detailed CAD model of a power pole. Figure 12 shows a 3d model for a power pole (left side) compared to the result for a landscape height modulation using DFAD data (right side). Figure 13 shows a SAR image with these two objects placed into a landscape. Using the landscape modulation results in a single bright patch and a solid shadow (right side). The 3d model for the power pole has been transformed into a finely structured SAR signature, with a realistic layover effect (pole looks like it's bent toward the sensor) and a detailed shadow.

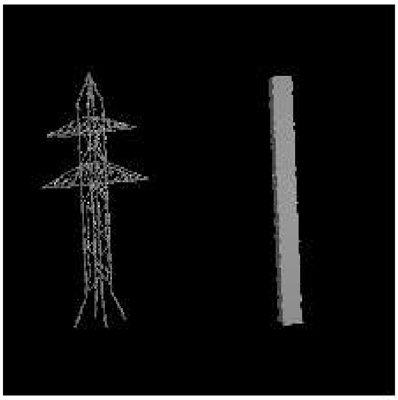


Figure 12 CAD model of a power pole (left) and power pole as height map modulation (right)

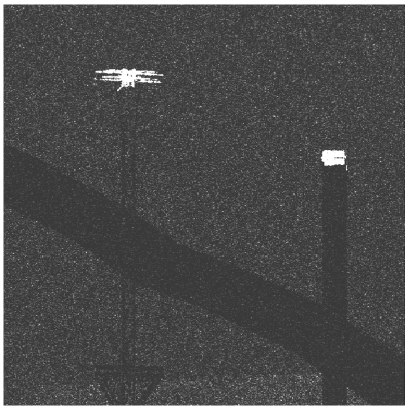


Figure 13 Synthetic SAR image using CAD model (left) and height modulation (right)

The realism of the generated images also depends on the quality and detail of the used terrain database. In order to improve the simulation quality it is useful to evaluate other databases as well. For Germany, an evaluation of the ATKIS and ALK data which are much more detailed than DTED / DFAD level 1 is planned. Both ATKIS and ALK data are constrained to Germany and stringent access restrictions apply. The height data that have been acquired by the SRTM space shuttle mission don't have the required precision. Our future goal is to use VMAP data for the simulation which is an upgraded and more detailed version of the DTED / DFAD database. The following pictures (figures 14 and 15) illustrate the different degree of detail of DFAD and ATKIS for a typical area of Germany. ATKIS contains more roads, settlements and surface structure as is to be seen in figure 15.

Figure 14 DFAD sample, 2000x2000m

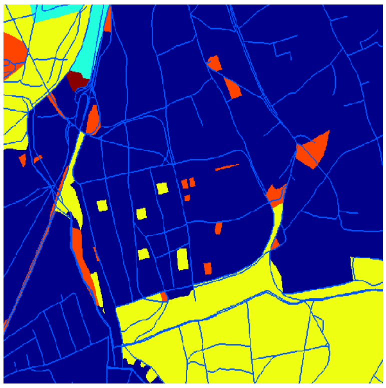


Figure 15 ATKIS sample, 2000x2000m for the same area as figure 14

3. VALIDATION

The appearance and quality of SAR imagery is influenced by many simulation parameters (e.g. chirp bandwidth, carrier frequency, signal-to-noise ratio), the realism and detail of CAD models and the detail of the terrain database. Because of these facts the imagery generated by a simulator does not necessarily look like imagery from real sensors. In order to be able to develop ATR algorithms on the basis of synthetic images that also work on real images, it must be assured that the synthetic images look as similar to the real ones as possible. For this reason it is necessary to develop methods which allow for objective comparisons between real and synthetic pictures of given scenes. In figure 16 synthetic imagery based on different terrain data are compared. The image rendered on the basis of DTED data (left) shows less detail than the ATKIS-based image (right).

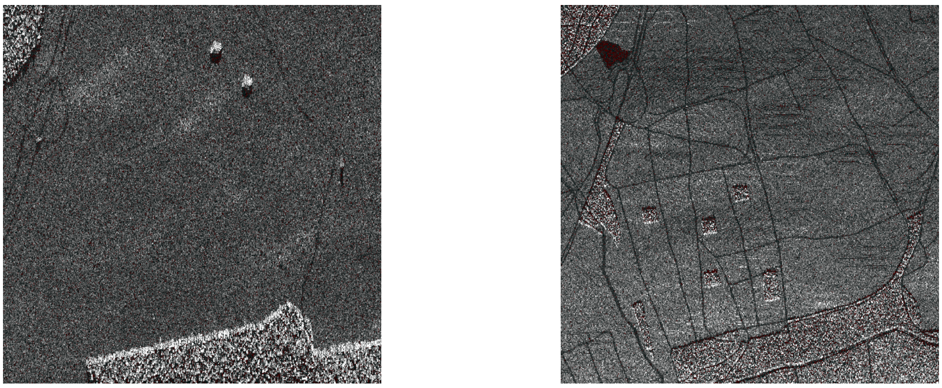


Figure 16 Comparison of synthetic SAR imagery of the same landscape area using DFAD/DTED data (left) and ATKIS data (right)

A classical approach for validating imagery is statistical analysis of image properties. Histogram evaluation can help to assure that typical image properties like its gray value distribution are realistic. These distributions vary in a typical way depending on the processing parameters of the image. There are property measures which can be employed for comparing images like the „co-occurrence matrix“ [4]. The co-occurrence matrix determines a value for the gray value arrangement in an image. It is the basis of many image property measures.
It is also possible to train ATR algorithms on specific image features and to use the comparative performance in real and synthetic images as a measure of similarity. Work in this area has just begun.

4. APPLICATIONS

4.1. ATR training

Doing ATR training on synthetically generated imagery offers several obvious advantages. Besides from being much cheaper and easier than recording real SAR imagery, it is easy to set up target scenes and put them on different backgrounds. For every object in a scene the type, location and orientation are always known exactly, which is a pre-condition for the learning process. It is very convenient to have the possibility of automatically generating mask images, because in many cases a lot of imagery is required to get an ATR algorithm working according to its specifications. Manually drawing masks for large amounts of imagery drawing can be very time consuming and error prone, so automatically generating masks means getting better ATR results in less time. In order to make a learning based approach rotation independent, it needs rotated images of the same object as input. These are also very easy to obtain with synthetic pictures. Moreover it is possible to simulate many different sensor types using a single tool as long as the sensor's properties are known.

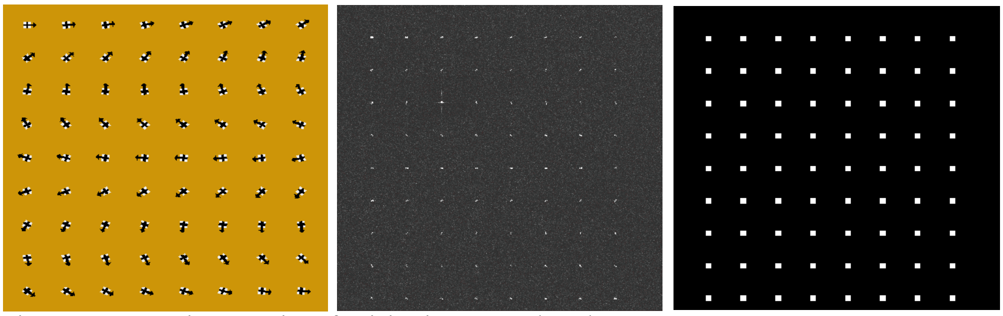


Figure 17 Automatic generation of training imagery and masks

Figure 17 shows a training scene with an object rotated in steps of 5 degrees. The arrows indicate its directions (left image) The synthetic SAR image that was generated from these data and the corresponding mask for ATR training are shown in the middle and right image. After a training scene has been set up, the mask image is generated automatically together with the SAR image. This can be done for any scene by activating a single checkbutton in the GUI. Using additional scripts it is easy to save scenes for repeated use (e.g. with different targets placed in them) or to rotate scenes. The result of rotating a whole scene is illustrated in figure 18. Note that the shadows always point in the same direction – away from the sensor which can be imagined to be located above the scene.

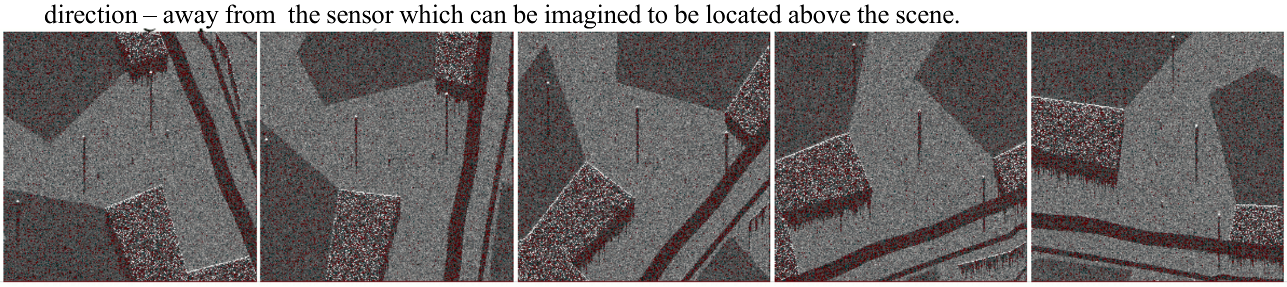


Figure 18 Automatic generation of training imagery and masks

4.2.Integration with flight simulator

The flight simulator at EADS is used for the ground training of future Eurofighter Typhoon pilots. The Simulation and Scenario Host contains a simulated aircraft and avionic model of the Eurofighter. The Aircraft Simulation comprises models for all flight critical systems as well as for the environment. Besides the human-piloted aircraft, other aircraft (friendly and enemy forces) are simulated. A graphical user interface allows easy start-up and operation. The Simulation and Scenario Host feeds the simulated aircraft and avionic model data to the cockpit's displays.

The cockpit displays are driven by PCs running the Linux OS. A one channel projection visual system shows the outside view of the simulated aircraft. Overlayed to this outside is a HUD projection. A sound system handles audible warnings and sound effects (engines, gun, etc.).

Besides the many computers that make up the cockpit environment and the flight simulation there are some more computers with very specific tasks. The collaboration of these computers is illustrated in figure 19.

There is a *mission planning computer* which plans flight routes according to the special geometry of long range SAR imaging. One of the more serious problems there is area shadowing which is very prominent because of flat incident angles. The waypoints that have been planned by the mission planner are then transferred to the central *simulation control computer* which distributes the data to the *cockpit* for visualisation. When recording waypoints are reached the *SAR simulator* is triggered to calculate an image. The image is then transferred to the *avionics development computer* where the ATR algorithms process it. The result is returned to the *simulation control computer* which relays it to the cockpit for visualisation.

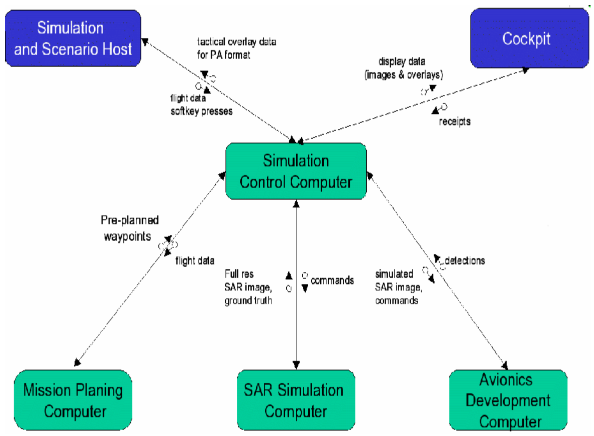


Figure 19 Components of flight simulation

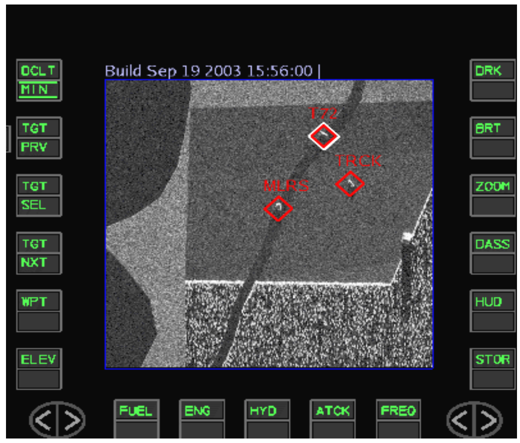
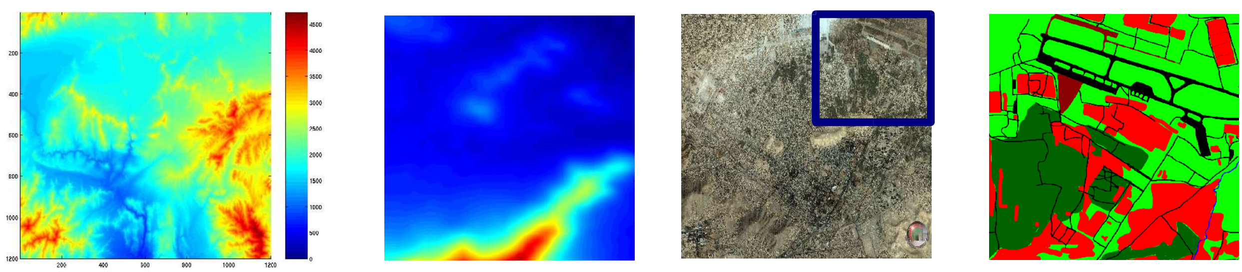


Figure 20 Screenshot of ground attack display

An example for visualisation of the SAR image together with classification results is shown in figure 20. The SAR image is contained within the blue frame. Symbols overlayed in red mark target positions and their types.

5. USING EXTERNAL DATABASES

For the application of a SAR simulator in mission related environment, it is relevant to have good terrain data of the scenario in question. This might not be the case for crisis regions like Afghanistan. Anyway, it is still possible to extract some of this information from public data. The following example illustrates a possible approach on the example of the Kabul airport. For elevation data the SRTM (shuttle radar topograhy mission) data was used, which is available on the internet for the whole surface of the earth at a 3 arc second resolution. The cultural data were extracted from satellite imagery in the visible spectrum. This can be done manually as in our case or automatically using texture classification algorithms.



(d) (a) (b) (c)

Figure 21 Intermediate steps in the creation of SAR imagery from alternative data, from left to right: SRTM tile (a), extracted height map for Kabul airport (b), satellite image (c) and extracted cultural data (d)

Figure 21 a shows the SRTM tile for a latitude of 34 and longitude of 69 degrees that contains both Kabul and its airport. A map (not shown) was used to determine the coordinates for the airport and to do the extraction of the corresponding height data (21b). A satellite image (21c) was used to extract feature information by overlaying the image with a transparent layer and painting homogenuous areas in the same color. The resulting image is shown in figure 22. The image was created using DoSAR parameters. It spans an area of about 2400x2400m and is simulated in X-Band. The pixel resolution is 0.57m, the elevation angle is 57° and the height of the sensor platform is 8km. Forested areas were processed using the height map post-processing introduced in chapter 2.4 and a couple of airplane models were placed in the scene for better realism.

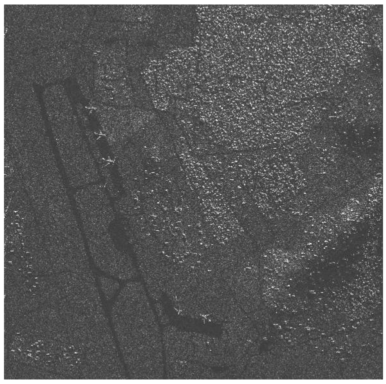


Figure 22 Artificial SAR image of Kabul airport

6. CONCLUSIONS AND FURTHER WORK

A system for dynamically generating SAR imagery from digital terrain databases was developed. An evaluation of several parameters influencing image realism was done. Approaches for improving image realism and database enrichment were presented. The usability of synthetic imagery for ATR training and for the integration into a combat flight simulator were illustrated. A lot of work remains to be done concerning the validation of the imagery. Statistical and ATR based approaches are to be considered.

A new SAR image generator is currently developed that includes spotlight mode, IMU deviations simulation and squint angles. The currently used statistical methods for simulation of SAR typical effects will be replaced by precise computations of the physical effects.

7. REFERENCES

[1] Kibbe, McDowell: “*Man-machine interface with simulated automatic target recognition systems*“, AGARD, Avionics Panel Symposium, Madrid, Spain, 1992.

[2] Barbato: „*Integrating voice recognition and automatic target cueing to improve aircrew-system collaboration for air-to-ground attack*“, RTO Systems Concepts and Integration (SCI) Symposium, Ottawa, 1998.

[3] Stahl, Haisch, Wolf: “*Automatic Target Recognition Flight Prototype for Police Helicopters*“, SPIE Proceedings, 2002.

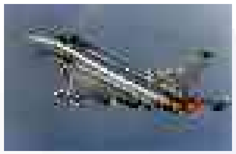
[4] Fries: „*Messung und Modellierung der Leistung von Kantenoperatoren*“, Fraunhofer Institute, Karlsruhe,2003.

Generation of synthetic SAR imagery for ATR development

MATRIX 2005

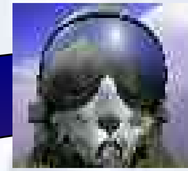
Heiko Seidel

Motivation



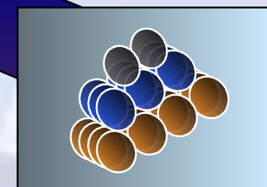
IR
VIS
SAR

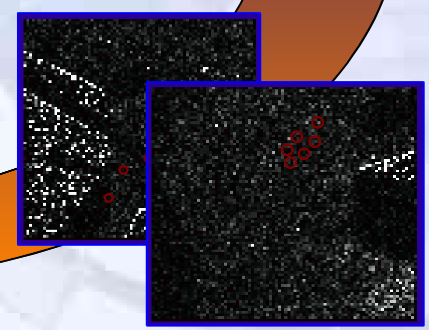
tendency:
more imaging sensors



increasing
workload

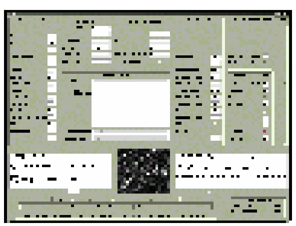
training-based ATR





need for training imagery

low availability
of real SAR
imagery

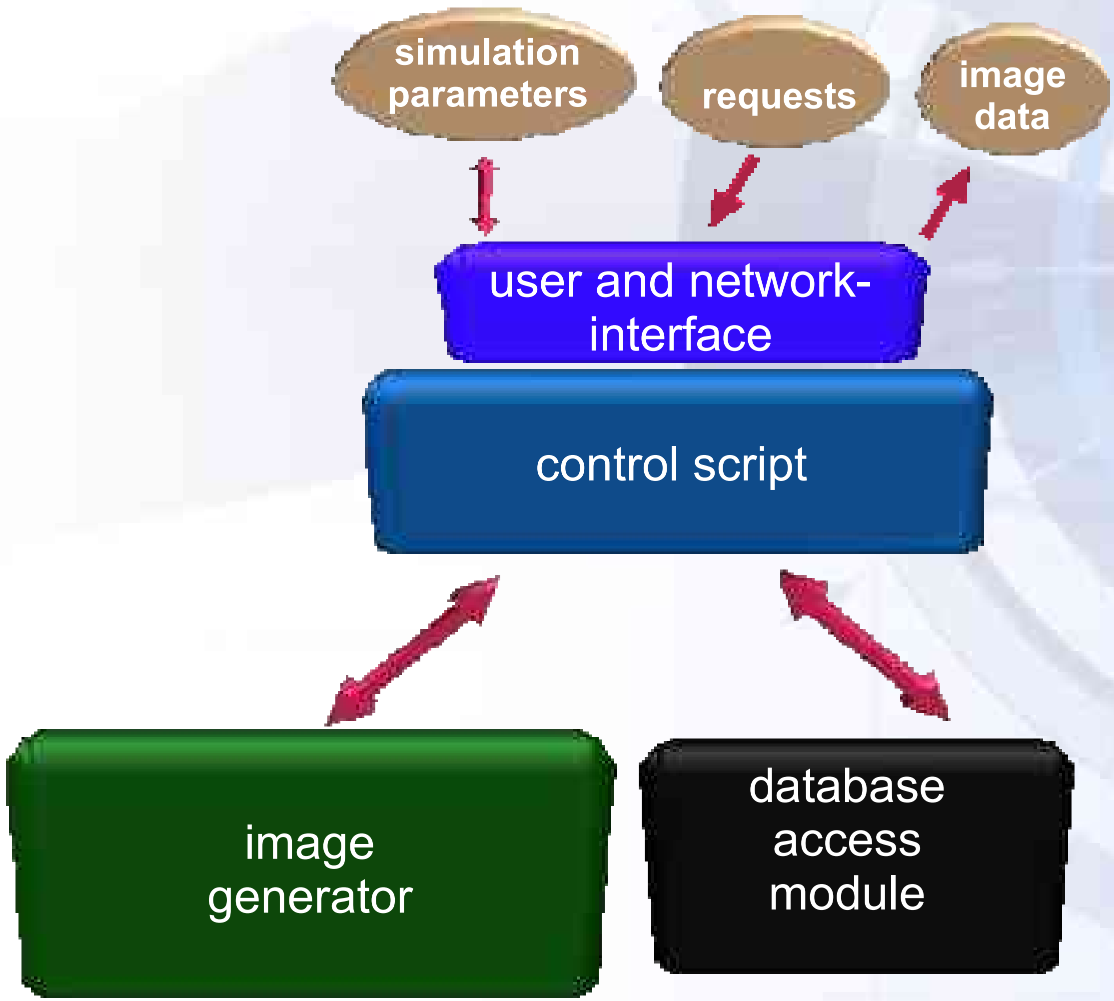


development of SAR
simulator

Overview

- Introduction to EADS SAR simulator
- Image enhancement
- Validation
- Applications of artificial SAR imagery
- External databases
- Outlook

Simulation components



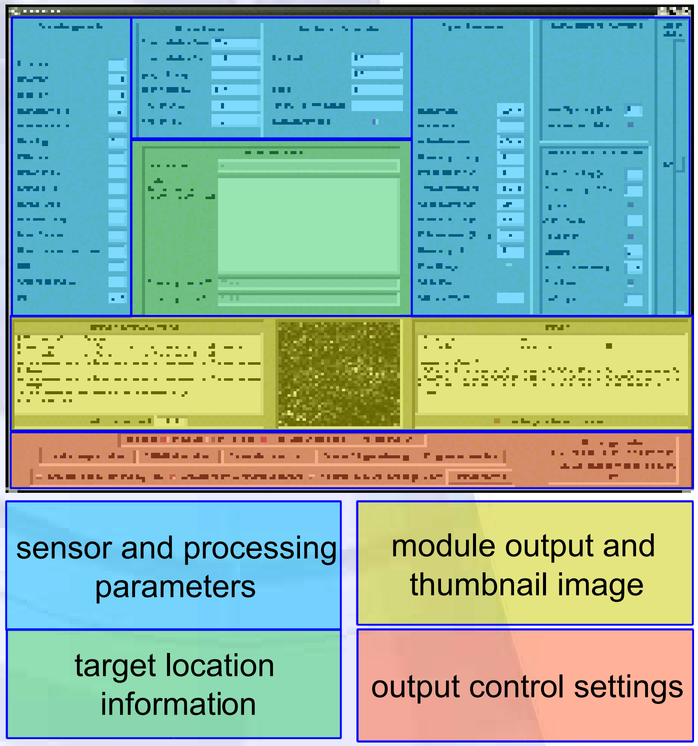


Image generator: process of image synthesis

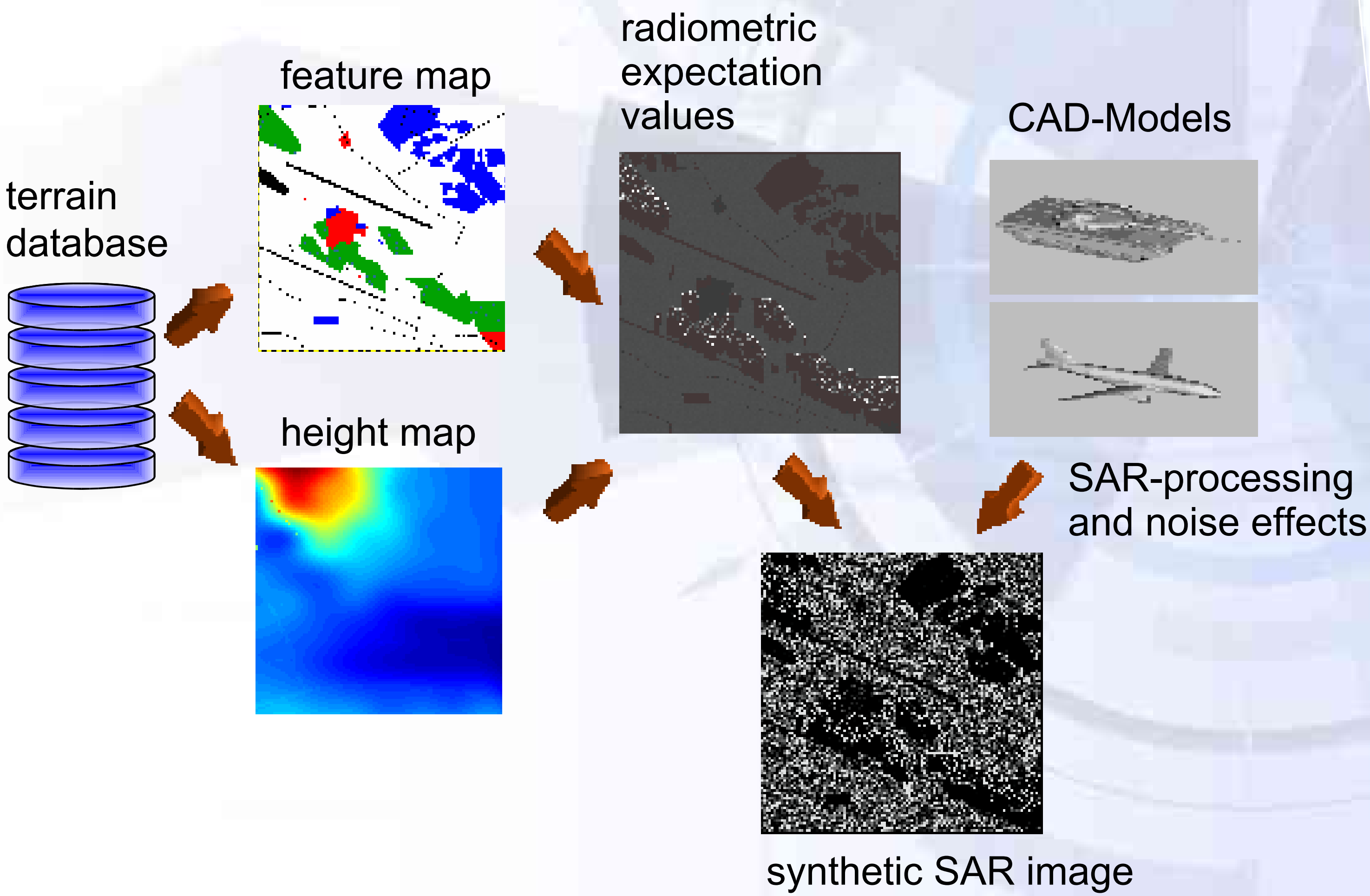
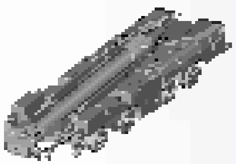
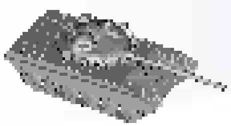


Image generator: 3d models and level of detail

models coming with SARVIEW

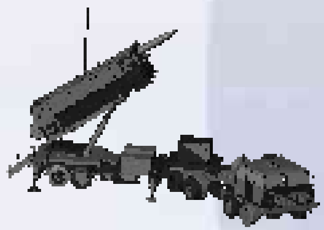


Scud-Launcher
vertices : 28187
surfaces: 56278

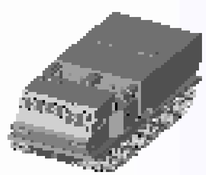


T-72
vertices : 38738
surfaces: 66634

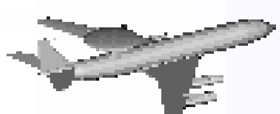
models from Internet



PATRIOT missile launcher unit
vertices : 83872
surfaces: 163512

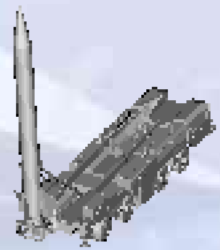


MLRS
vertices : 26062
surfaces: 46068

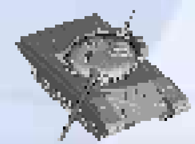


AWACS E3A Sentry
vertices: 4466
surfaces: 8932

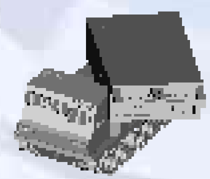
self-modified models



Scud-Launcher
„ready for launch“



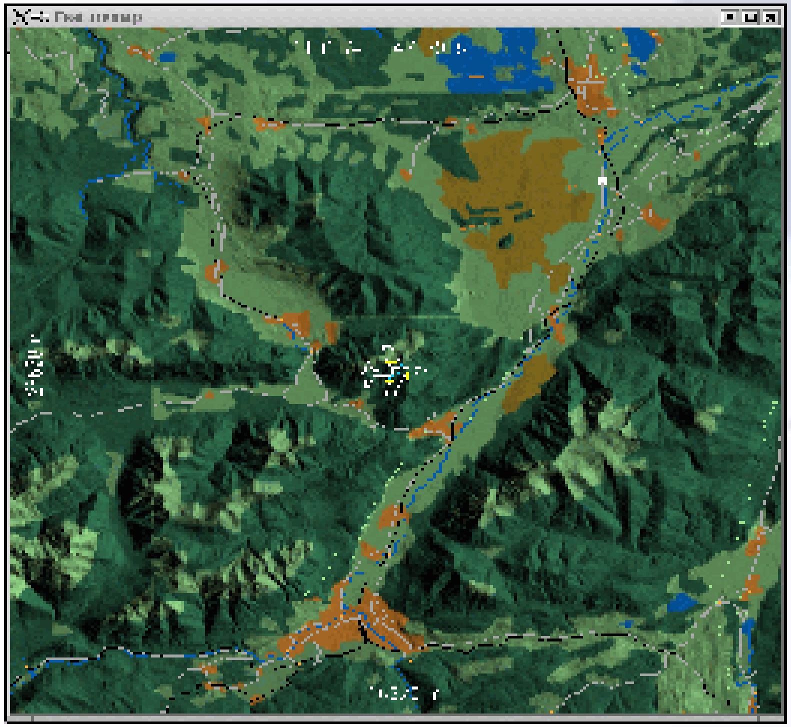
T-72



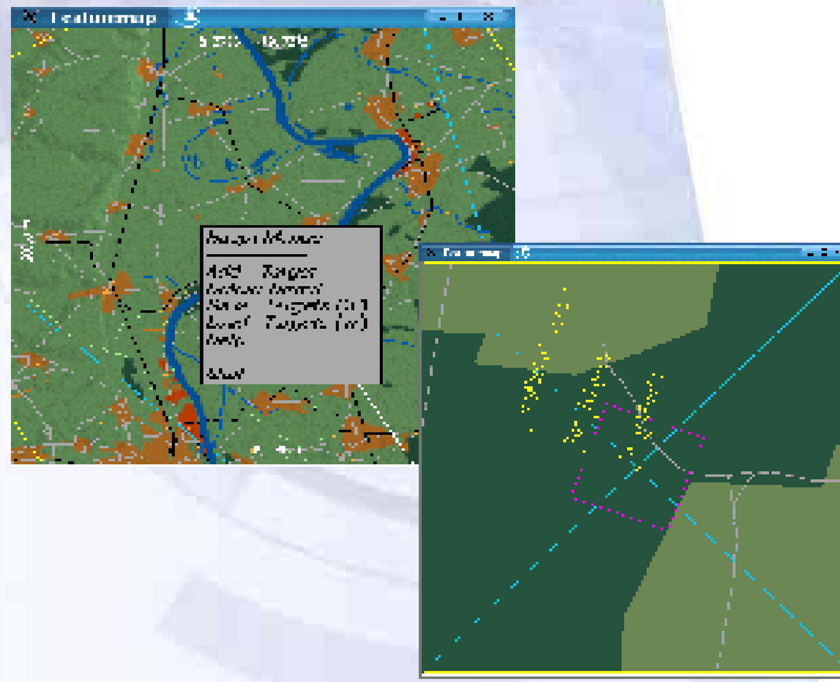
MLRS
„ready for launch“

Terrain database

- area calculation
- input map generation
- target coordinates

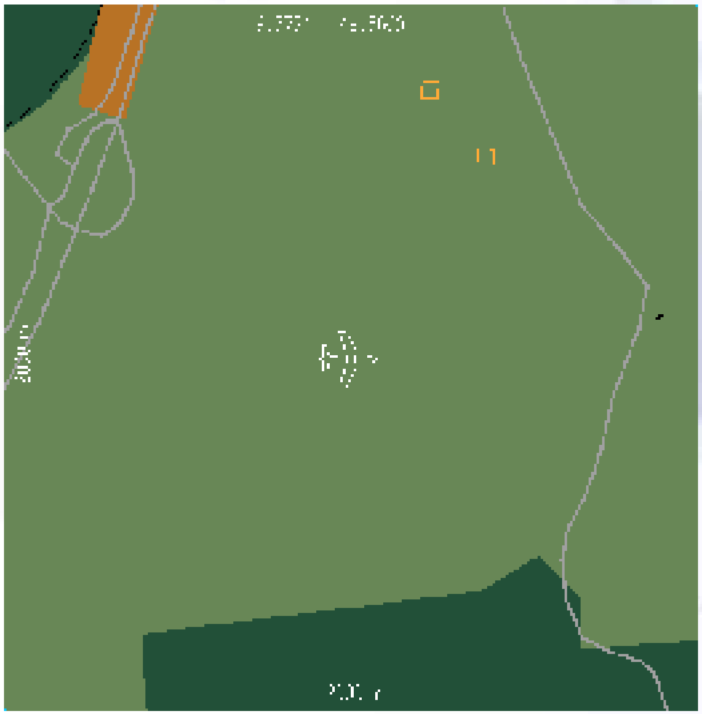


- edit target database
- add other objects



Comparison with other databases

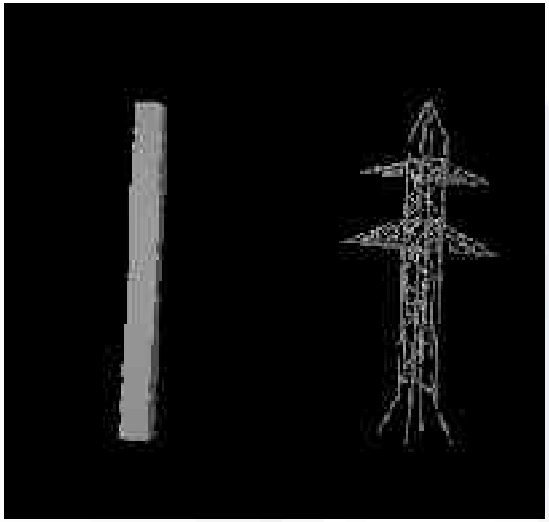
DFAD level 2

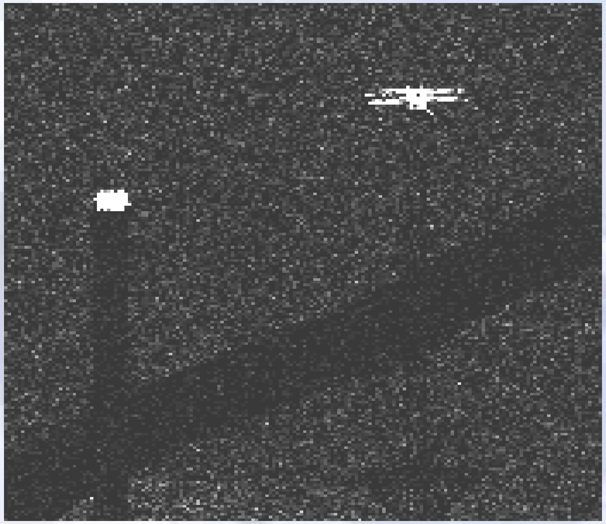


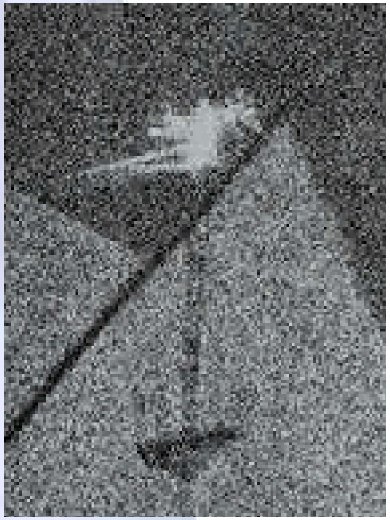
ATKIS

- ATKIS = amtliches topographisch-kartographisches Informations-System
- different level of detail
- realism of SAR imagery

Database extensions : power poles







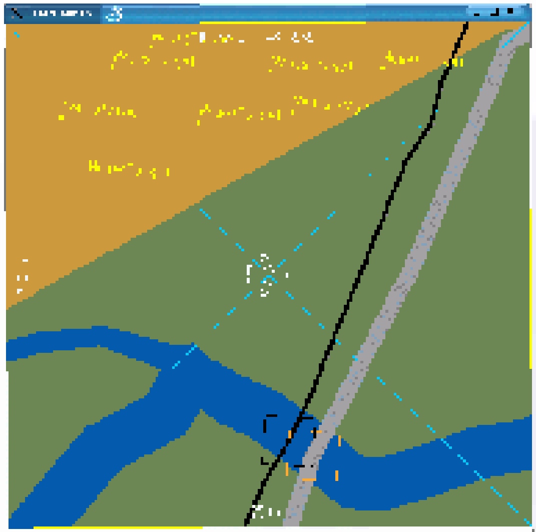
- DFAD: only dimensions of man-made objects
- two possibilities:
  - model data into landscape or
  - extract coordinates and use 3d model

- left: landscape modulation (height and surface cover)
- right: 3d model
- 3d model yields more realistic simulation result

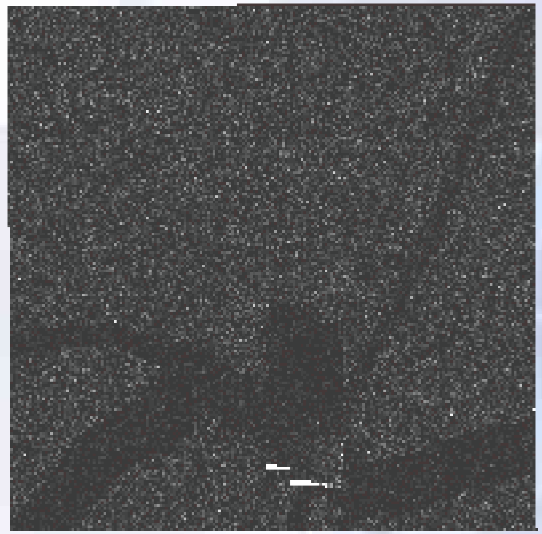
real SAR image

source: EADS, MiSAR, resolution 0.5m
in: Planet Aerospace, 1/2004

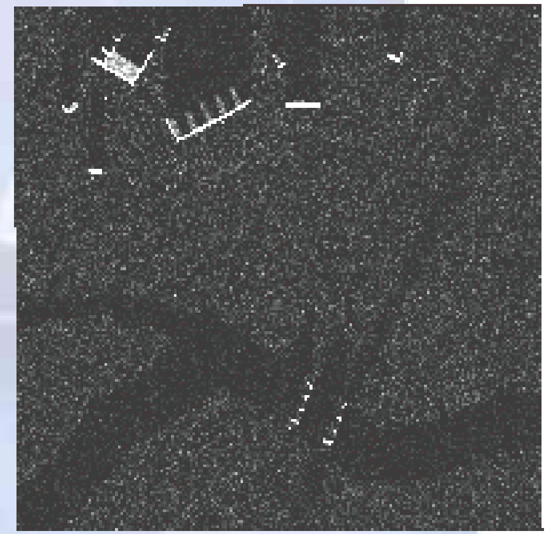
Database extensions : buildings



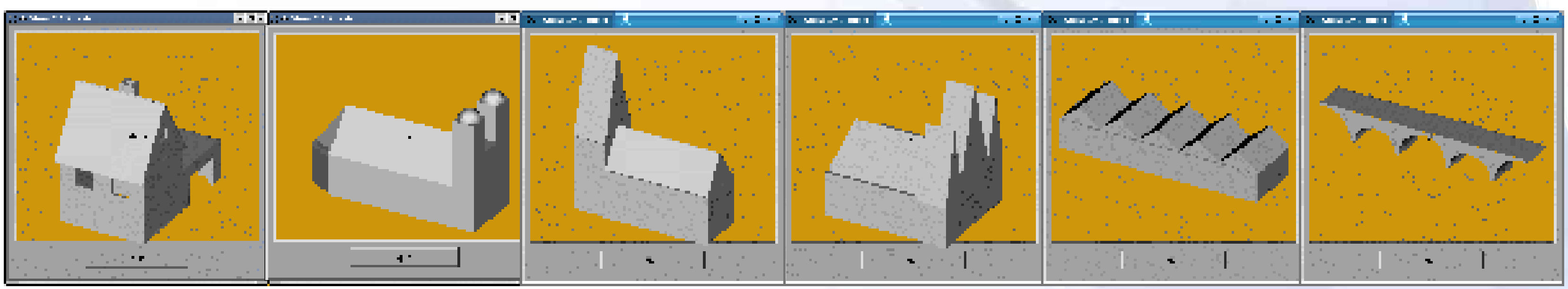
scene (DFAD)



SAR image



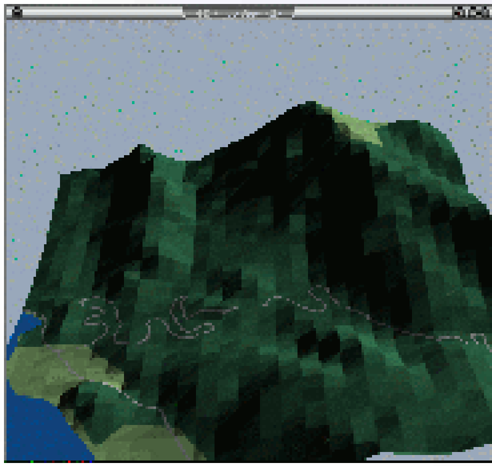
SAR image with added 3d models

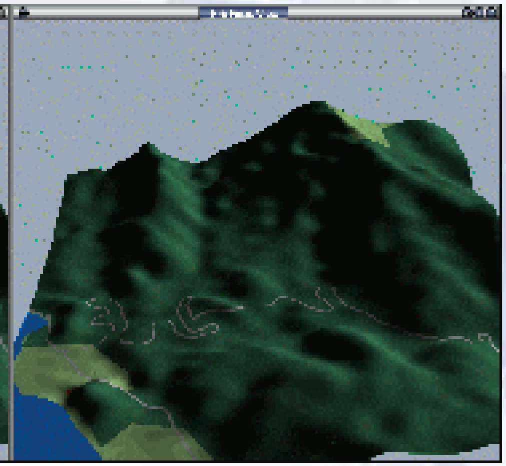


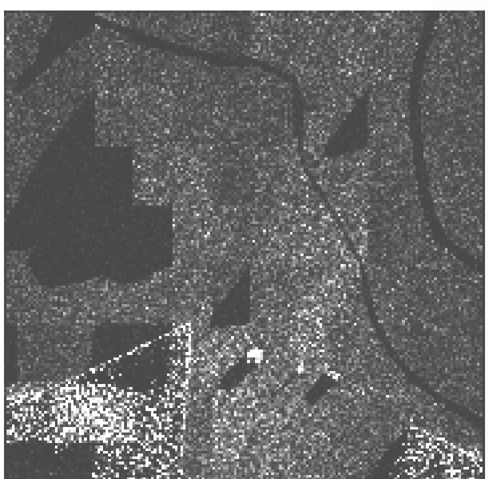
Height interpolation

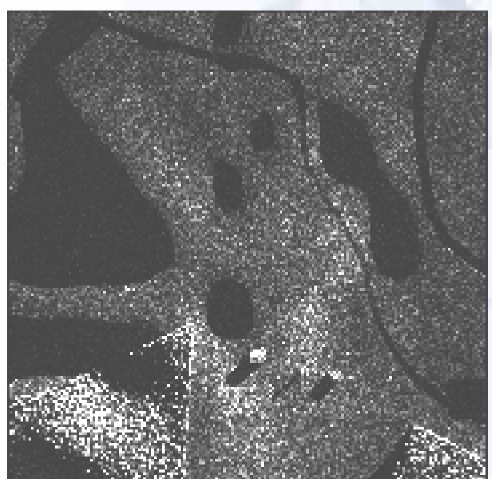
bilinear interpolation

spline interpolation



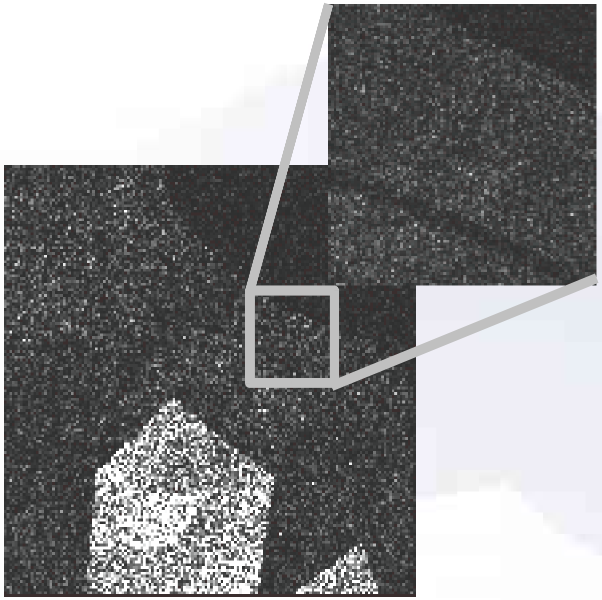




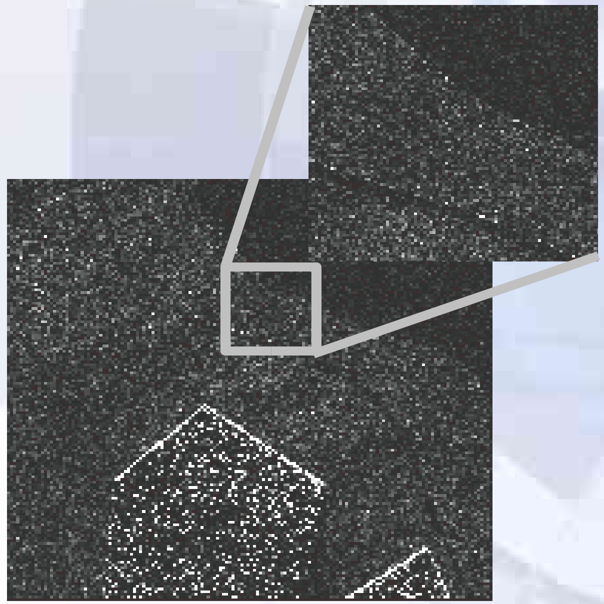


depression angle: 8°
carrier frequency: 9.6 GHz
chirp bandwidth: 200 MHz
resolution : 0.75 m

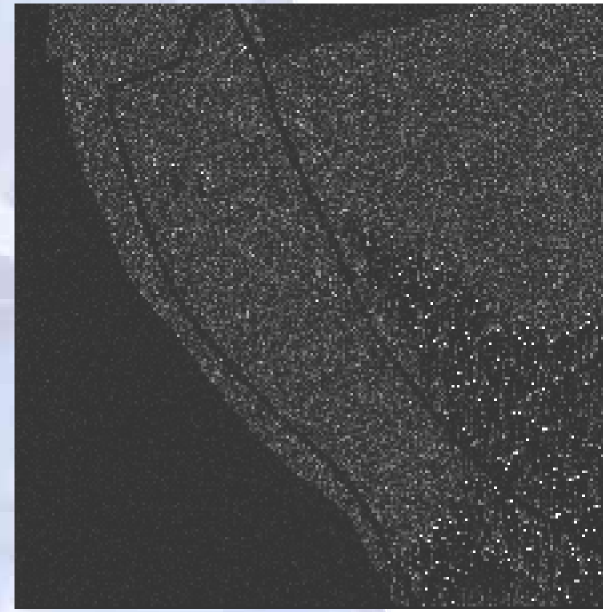
Database post-processing (1)



- no post-processing



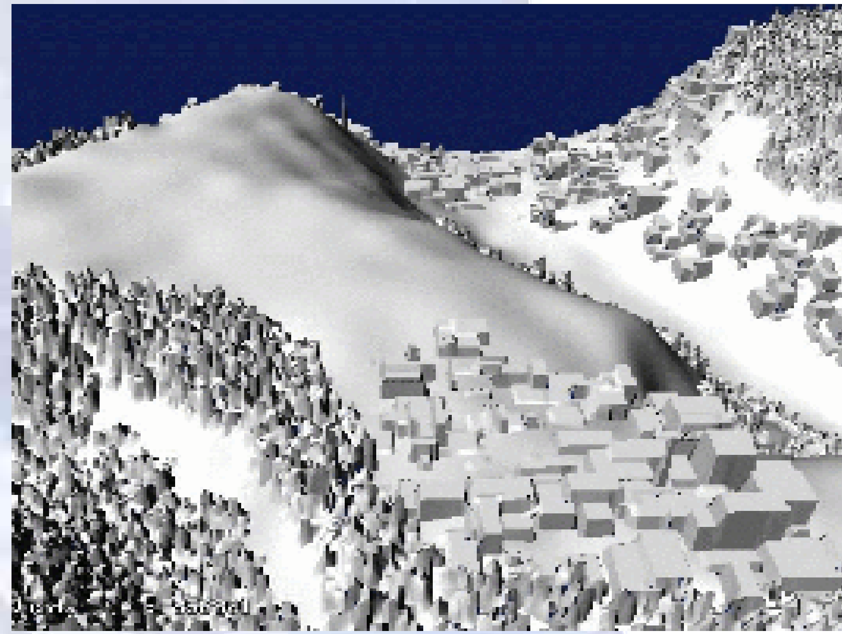
- forest height modulation
- road surface raised
- water surface lowered

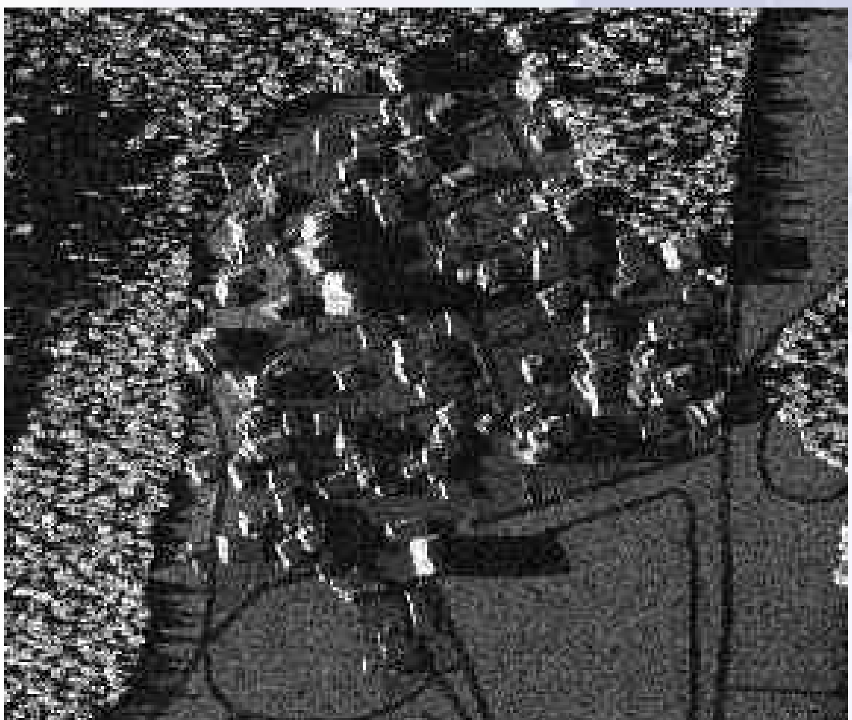


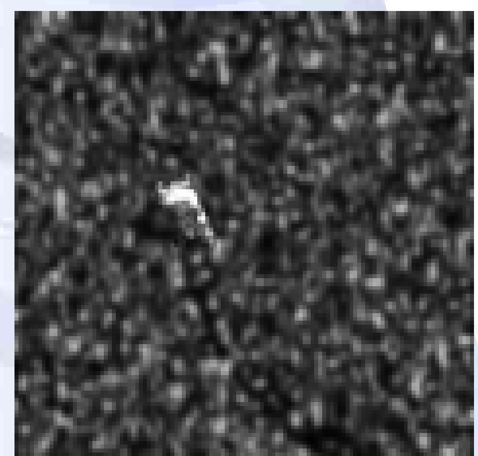
- single trees (resolution better than 1.5m per pixel)

Database post-processing (2)

- Improved post-processing algorithms for
  - urban areas
  - fields / meadows / shrubs
  - vehicle tracks







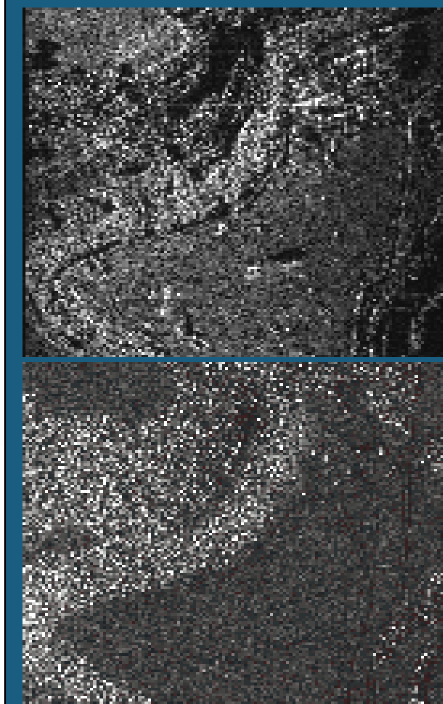
in collaboration with:

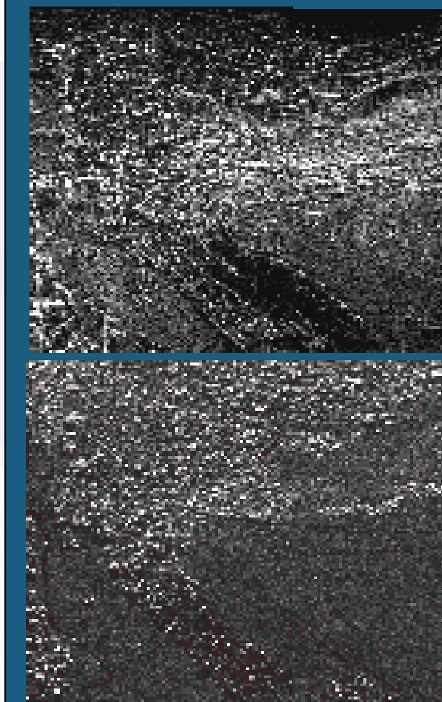
Fraunhofer Institut Informations- und Datenverarbeitung

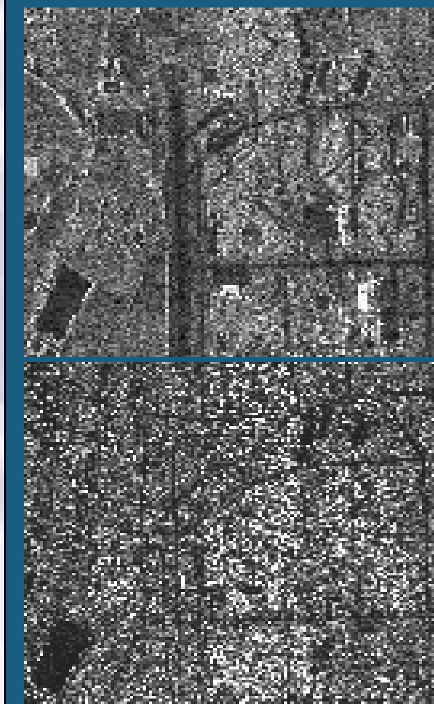
EADS DEFENCE & SECURITY

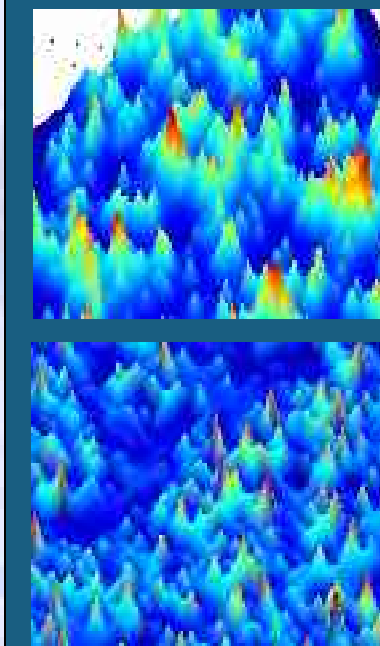
Validation

landscapes and modelling



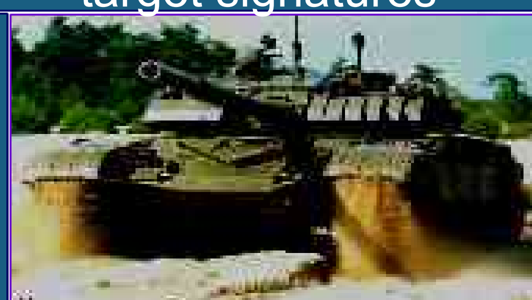


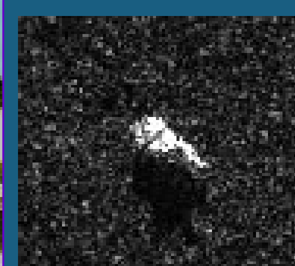




target signatures

T-72
simulated

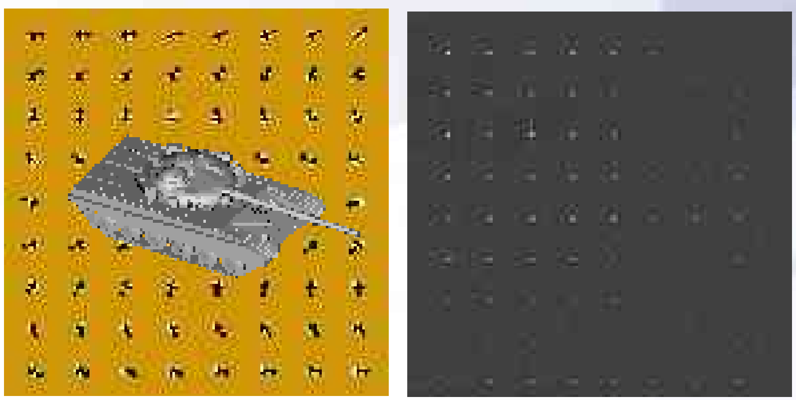




T-72
MStar

Sensor Simulation and ATR development

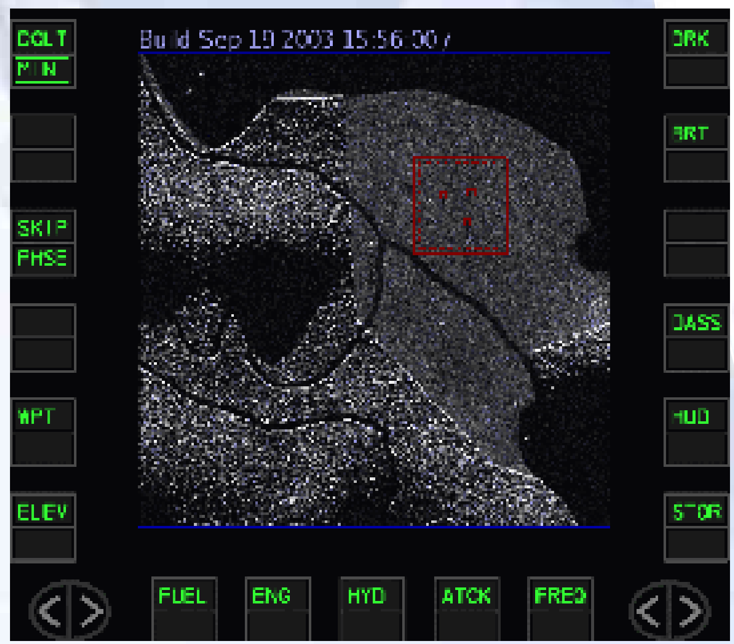
- definable scenario
- definable configuration of target objects
- precise ground truth knowledge



training scene

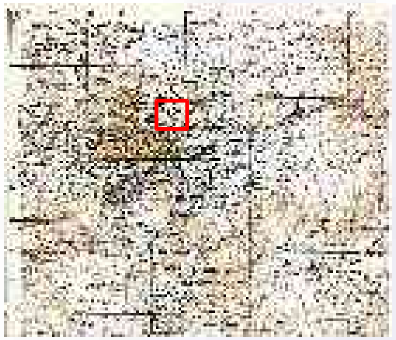
testscene in database and ground truth

The flight simulator at EADS

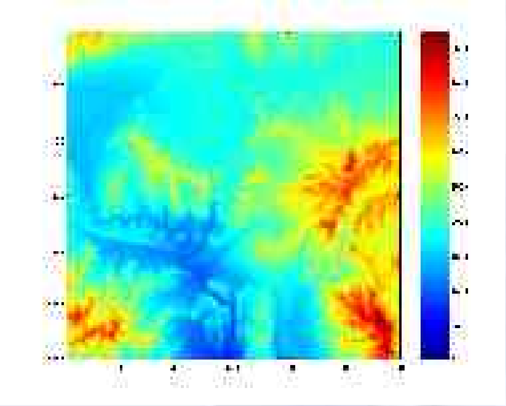


- environmental and aircraft models
- computer generated threats
- outside view and HUD projection
- SAR image from given aircraft position and sensor attitude

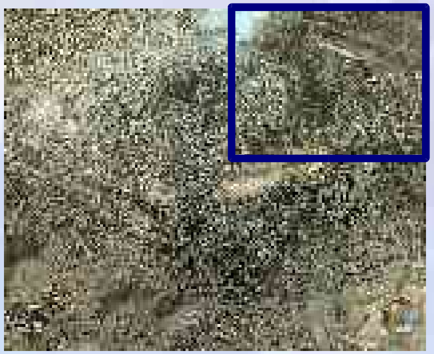
Simulations with external databases: example – simulating crisis areas



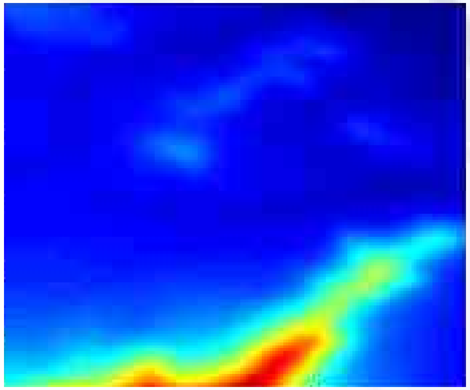
map of Kabul



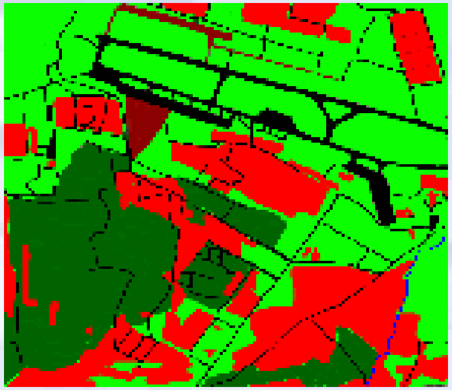
corresponding SRTM patch



satellite image

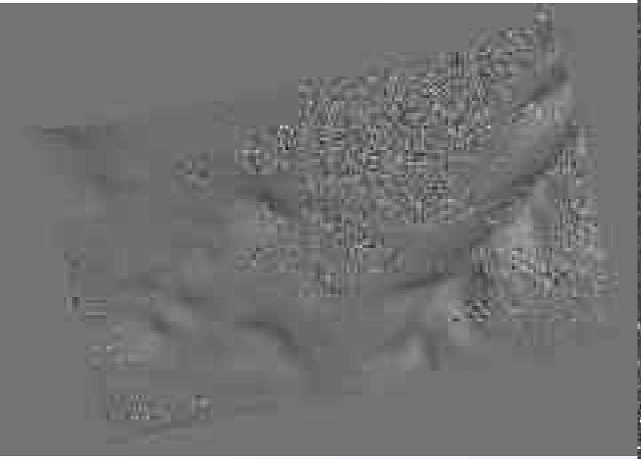


extracted height map

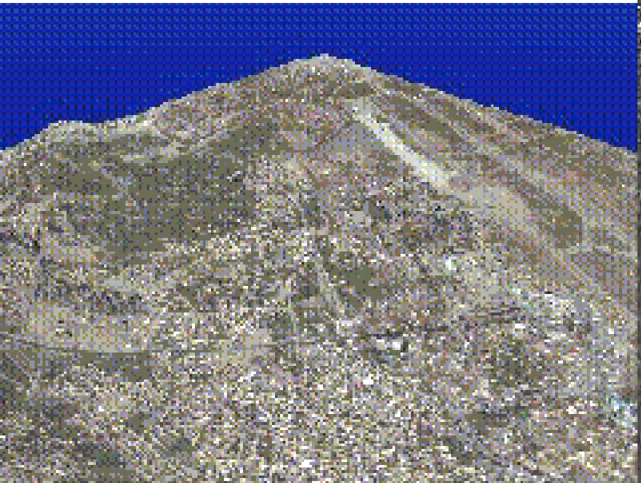


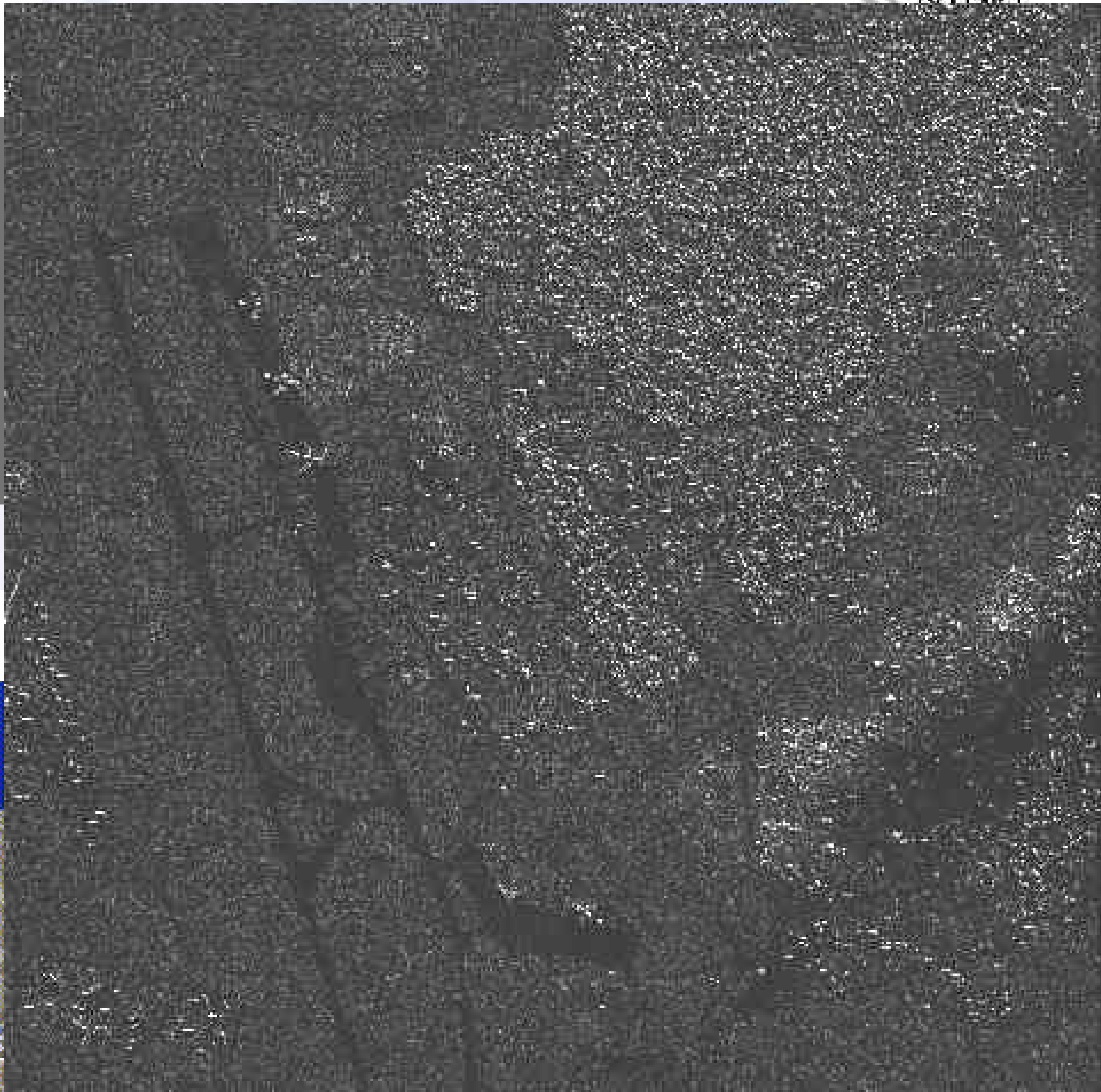
extracted feature map

SAR image



parameters:
DoSAR / height: 8 km

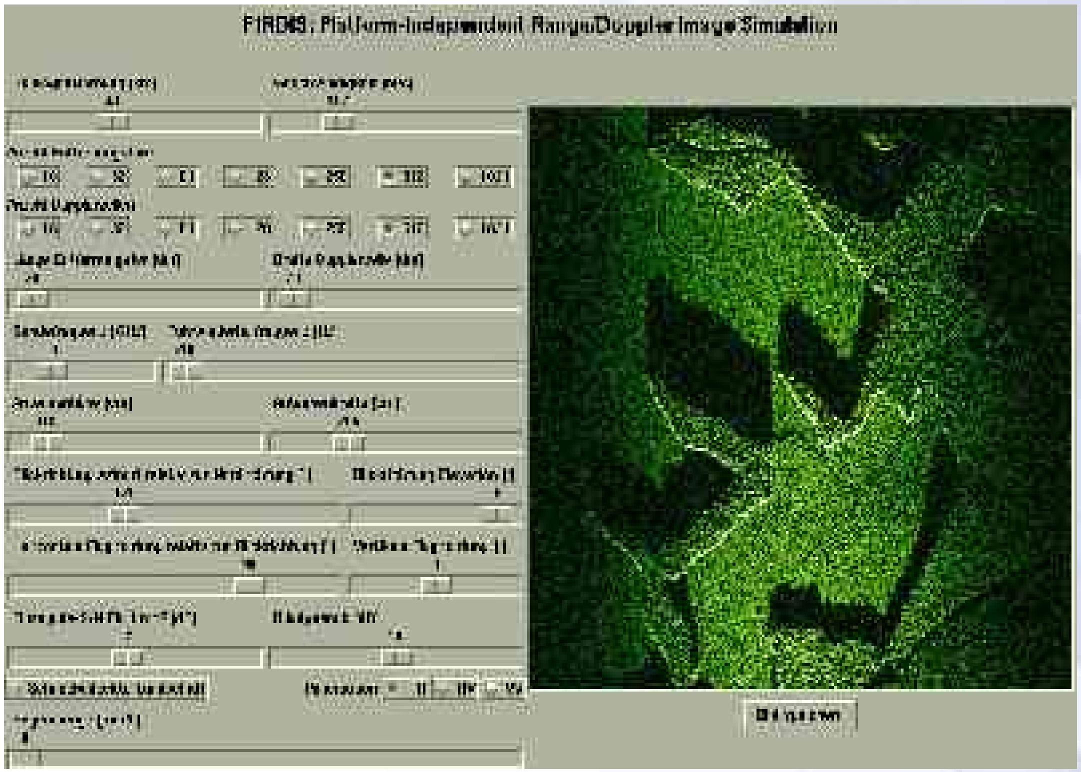


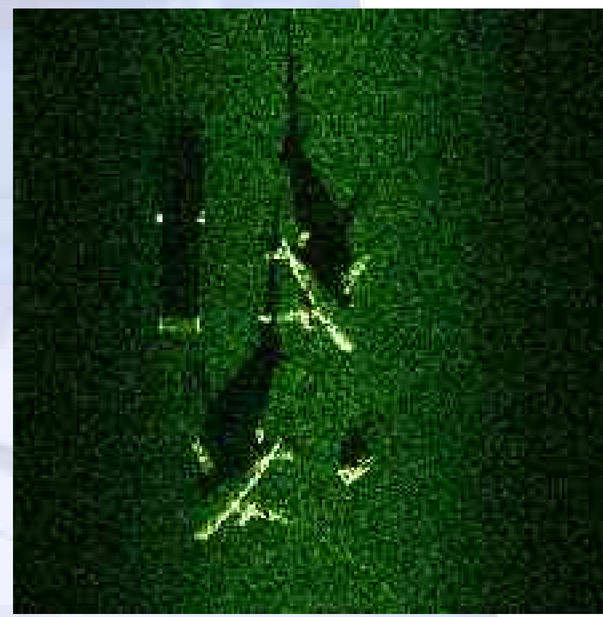


Summary

- System for online generation of SAR images integrated
- Database post-processing algorithms for realism improvement developed
- Validation approach being defined
- New image generator being developed
- Application examples
- Use of alternative terrain data demonstrated

Outlook





- New image generator PIRDIS for simulating:
    - Squint angles
    - IMU deviations
    - more RCS functions
    - Enhanced target/target and target/surroundings interaction

Questions
???

Additional Material

Control script : data flow